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Applications of elastic full waveform inversion to shallow seismic surface waves

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Shallow-seismic Rayleigh waves are attractive for geotechnical site investigations. They exhibit a high signal to noise ratio in field data recordings and have a high sensitivity to the S-wave velocity, an important lithological and geotechnical parameter to characterize the very shallow subsurface. Established inversion methods assume (local) 1-D subsurface models, and allow the reconstruction of the S-wave velocity as a function of depth by inverting the dispersion properties of the Rayleigh waves. These classical methods, however, fail if significant lateral variations of medium properties are present. Then the full waveform inversion (FWI) of the elastic wave field seems to be the only solution. Moreover, FWI may have the potential to recover multi-parameter models of seismic wave velocities, attenuation and eventually mass density.

Our 2-D elastic FWI is a conjugate-gradient method where the gradient of the misfit function is calculated by the time-domain adjoint method. The viscoelastic forward modelling is performed with a classical staggered-grid 2-D finite-difference forward solver. Viscoelastic damping is implemented in the time-domain by a generalized standard linear solid. We use a multi-scale inversion approach by applying frequency filtering in the inversion. We start with the lowest frequency oft the field data and increase the upper corner frequency sequentially. Our modelling and FWI software is freely available under the terms of GNU GPL on www.opentoast.de.

In recent years we studied the applicability of two-dimensional elastic FWI using numerous synthetic reconstruction tests and several field data examples. Important pre-processing steps for the application of 2-D elastic FWI to shallow-seismic field data are the 3D to 2D correction of geometrical spreading and the estimation of a priori Q-values that must be used as a passive medium parameter during the FWI. Furthermore, a source-wavelet correction filter should be applied during the FWI process. Smooth initial models obtained from the analysis of the first arrivals of body waves are important and seem to be sufficient. The L2 norm of normalized seismograms is a robust misfit criterion in case of field data but limits the reconstruction of deeper structures.

Above a predominantly depth dependent structure consisting of fluviatile sediments the FWI is able to reduce the misfit successfully up to 70 Hz. The final model obtained is in a good agreement with a 1-D model obtained by the inversion of dispersion curves. In a second field data set acquired above strong shallow lateral variations of subsurface properties, the FWI is able to reduce the misfit up to approximately 20 Hz only. Possible reasons for the failure at higher frequencies are non-linearities of the misfit function at higher frequencies, unknown small-scale 3-D medium heterogeneities that violate our 2-D assumption, or insufficient consideration of the frequency dependency of attenuation.